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# Influence of Heat Treatment on Wear Resistance of Cast Parts with a Hard-Alloy Coating

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**ABSTRACT:** The article presents research materials on the structure and properties of hard-alloy coatings obtained in the process of casting products using gasified models. The composition and properties of 35GL steel were studied, as well as the hardness and microhardness of the surface and subsurface layers of cast products. The relative wear resistance of tests carried out in laboratory and field conditions is analyzed. Final heat treatment modes with double phase recrystallization for cast parts were performed. It is shown that heat treatment with double phase recrystallization increases the wear resistance of hard-alloy coatings and finished products by 3-4 times.

**KEY WORDS:** Gasified model casting, hard-alloy coating, high-carbon steel, hardness and microhardness, microstructure, heat treatment with double phase recrystallization, abrasive wear resistance and durability.

## I. INTRODUCTION

It is known that many machine parts that work in direct contact with the soil are surfaced with hard alloys. This requires the use of fairly complex technological equipment, due to the high consumption of cast hard alloys and fluxes. It is more rational to obtain these parts by casting on expanded polystyrene gasified models with the simultaneous formation of a hard-wear coating [1,2].

This paper examines the internal structure and mechanical properties of products obtained by casting gasified models with hard-wear coatings before and after heat treatment.

When the insert from the powder of a high-chromium hard alloy comes into contact with a liquid metal, the solid crust of the casting is formed, the insert melts, the liquid phase of the insert interacts with the crust material, and after crystallization, the eutectic or non-eutectic compositions form on the surface of the structure of white high-alloyed cast iron. The transition from the wear-resistant coating to the base metal is quite sharp, although there are transition zones from the eutectic part to the eutectic, pre-eutectic and to the zone of the eutectoid steel. The presence and thickness of the over-eutectic zone depends on the thickness of the insert coating on the model, the over-eutectic zone is maximum at a coating thickness of 3.0 mm.

## II. METHODOLOGY

The technology for obtaining products by casting gasified models includes the production of a Styrofoam model. A liquid suspension is applied to the working surfaces of the Styrofoam model, consisting of consisting of a powder of a high-chromium hard alloy (table.1). in the manufacture of the suspension, polyvinylbutyraland a 4% solution of polyvinyl butyral in alcohol were used as a binder. The thickness of the coating layer h on the Styrofoam model was 2.0, 2.5 and 3.0 mm [2]. After drying the coating, the models were formed in quartz sand and filled with a liquid metal corresponding to the composition of high-carbon steel. When filling, the Styrofoam model burned out and the casting surface was saturated with carbon up to 0.8 % to a depth of 0.50-0.85 mm.

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**Table 1 Composition of high-chromium hard alloy**

| Content of components, in % | | | | | | | |
|---|---|---|---|---|---|---|---|
| Base | C | Cr | Si | Mn | Ni | W | Mo |
| Fe | 3,3-4,5 | 25-28 | 1,0-2,0 | 0,8-1,5 | 1,5-2,0 | 0,2-0,4 | 0,08-0,15 |

The microhardness within the thickness δ of the carbide coating varies widely. The highest microhardness of the samples obtained with the thickness of the coating layer on the model 2.0-2.5 mm. At the surface itself, a non-eutectic structure is formed with a large number of primary chromium carbides with a hardness of NV100 = 15300 MPa. At the same time, the microhardness of the metal base of the eutectic is 7300 MPa. At a depth of 0.4-2.5 mm from the surface, depending on the thickness of the insert, the structure of the base metal with a hardness of 2600 MPa is already observed.
The maximum hardness and depth of the wear-resistant layer are lower on models with a thinner hard-alloy coating, which is explained by the lower depth of the over-eutectic zone and its absence in the case of a coating thickness of 2.5 mm.
Phase x-ray diffraction analysis was performed by taking x-ray images from the surface of the hard-alloy coating. The research results showed that special carbides of the $Me_{23}C_6$ and $Me_7C_3$ types are formed on the surface of samples with wear-resistant coatings.
When manufacturing machine parts, it is necessary to ensure not only high wear resistance of working surfaces, but also a sufficient level of strength of the entire product. This is achieved by heat treatment. In this case, low-tempering was used in the manufacture of cast parts made of high-carbon steel. When quenched in oil, this steel has a low calculability, and an incomplete quenching structure is formed in the core of the product with a sufficient level of plasticity at a hardness of HRC=32-35.
At the same time, the wear-resistant coating is further strengthened. At the same time, the upper level of microhardness values does not change, but the lower level increases markedly from 7300 to 8500 MPa. This is due to the fact that when quenching the metal base of the structure undergoes a martensitic transformation.
Increasing the heating temperature for quenching from 900 to 1150°C leads to more significant structural changes. As the heating temperature increases for quenching, the thickness of the hardened layer increases. This is evidenced by microhardness data. The effective thickness of the hardened layer with a lower hardness level of 5000 MPa increases, which can be attributed to the diffusion of carbon atoms deep into the base metal.
The effect of the $T_3$ quenching temperature on the thickness of the hardened layer with a hardness of at least 5000 MPa is shown in table 2.

**Table 2 Dependence of the thickness of the hardened layer of samples of medium-carbon steel with a hard-alloy coating on the temperature of heating for quenching**

| h, mm | δ, mm | | | | |
|---|---|---|---|---|---|
| | before quenching | after quenching with $t_3$, °C, and low tempering | | | |
| | | 900 | 1000 | 1100 | 1150 |
| 1,0 | 0,1-0,3 | 0,6-0,7 | 0,6-0,7 | 0,9-1,0 | 0,9-1,0 |
| 1,5 | 0,3-0,4 | 0,6-0,9 | 0,7-0,9 | 0,7-0,9 | 1,0 |
| 2,0 | 0,6-0,9 | 0,8 | 0,9 | 1,4 | 1,4 |

An increase in the heating temperature for quenching leads to a more complete dissolution of secondary carbides in austenite. The primary carbides substantially coagulated. After quenching samples with a coating thickness

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(coating layer) of 2.0-2.5 mm at a temperature of 1100-1150$^{o}$C, a martensite structure consisting of 40-50% residual austenite and primary carbides is formed on the surface. Microhardness is reduced to 5000 MPa. At a depth of 1.4-2.6 mm from the surface, the amount of residual austenite decreases, and the microhardness increases to 8000 MPa. Further down the depth, the microhardness decreases again with a decrease in the carbon content in martensite.

## III. EXPERIMENTAL RESULTS

In some cases, heat treatment with double phase recrystallization is used to create optimal structure parameters in order to increase wear resistance and strength [3]. The first phase recrystallization is carried out with heating to extreme temperatures, when after cooling (quenching) a structure with the maximum dislocation density is formed. During intermediate release, excess phases are released as dispersed particles, and the dislocation structure is stabilized. The second phase re-crystallization with heating to the temperatures usually accepted for this steel ensures grain grinding and preservation of high dislocation density [3,4].

When quenching the carbide coating, extreme temperatures were also observed. The dislocation density found by the physical width of the x-ray line (220) of the α-phase [5] takes the maximum value after quenching with 1100$^{0}$C.

After intermediate tempering at 650$^{0}$C, secondary quenching at 900$^{0}$C and low tempering, wear-resistant coatings in the metal base have a martensitic structure with a high density of dislocations, dispersed particles of secondary carbides and coagulated primary carbides.

The change in the density of dislocations of the α-phase depending on the quenching temperature of the carbide coating at the final tempering from 200$^{o}$C for 1 h is shown in table 3

**Table 3Dependence of the dislocation density of the α-phase p on the heating temperature for hardening of the hard-alloy coating**

| Heat treatment | Dislocation density p*1011 cm$^2$, at $t_3$, $^{o}$C | | | |
|---|---|---|---|---|
| | 900 | 1000 | 1100 | 1150 |
| Quenching | 0.35 | 3.49 | 4.82 | 1.98 |
| Repeated phase recrystallization | 2.24 | 2.14 | 3.62 | 2.33 |

Samples with hard-alloy coatings obtained by casting using gasified models with an insert of 2.0 mm and 2.5 mm form a structure consisting of eutectic carbides and martensite on the surface. Due to the strong doping of the solid solution (austenite) at a depth of 1.4-2.3 mm from the surface, a lot of residual austenite is found. However, the microhardness does not decrease below $NV_{100}$ = 500 kg / mm$^2$. At a depth of 1.5-2.4 mm from the surface, a purely martensitic structure is observed and microhardness increases. Further, a monotonous decrease in microhardness is observed along the thickness of the composition, and the total thickness of the layer with a hardness of at least $NV_{100}$ = 500 kg/mm$^2$ reaches 1.8-2.4 mm.

The microstructure clearly shows the structure of the needle martensite, residual austenite, primary carbides and a sublayer of high-carbon martensite (Fig.1,a). A similar pattern is observed when considering the microstructures of the layer in samples obtained by casting gasified models with inserts of 2.0 and 2.5 mm. In these cases, primary carbides and martensite are observed on the surface itself. Microhardness is high, and at a depth of 1.3-2.4 mm from the surface, the structure is martensitic with a large amount of residual austenite (Fig. 1, b, c).

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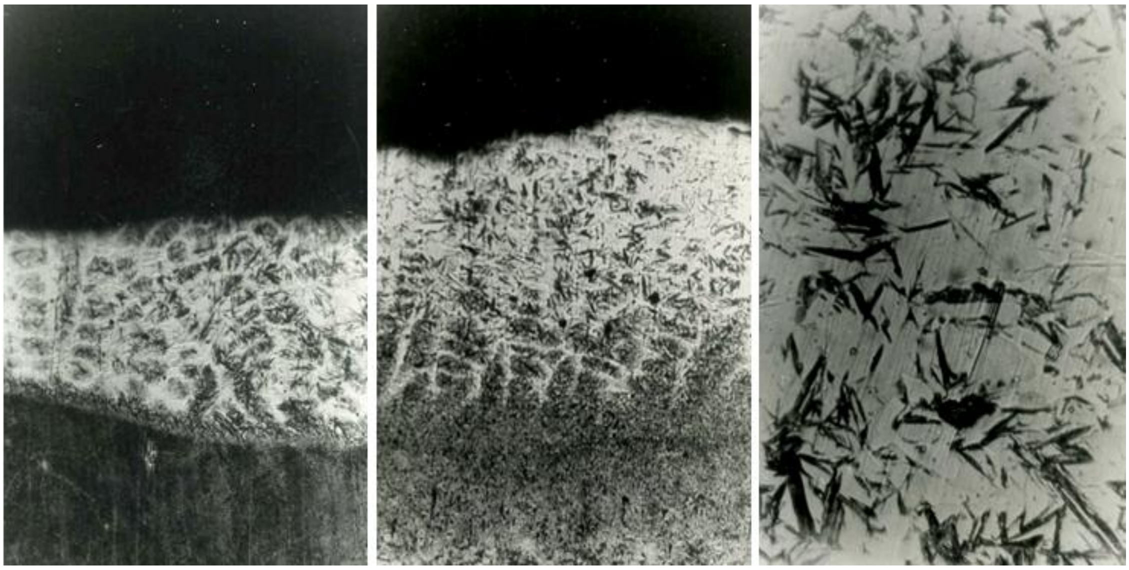


Fig. 1. Microstructure of the hard-alloy coating and high-carbon sublayer in samples: a-coating thickness of 1.0 mm after quenching with a heating temperature of 1100°C and tempering 200°C; b-coating thickness of 1.5 mm after quenching with a heating temperature of 1100°C and tempering 200°C; C-microstructure of coarse grained martensite and residual austenite at a depth of 0.3 mm from the surface of the hard-alloy coating. X200

All hard-alloy coatings are tested for abrasion resistance after heat treatment. Tests on the abrasive wear of coatings in time t were performed on the friction machine ПВ-7 with an unshackled abrasive material according to the method [6,7]. The test results are shown in (Fig. 2). the hard-alloy coating dramatically increases wear resistance: the greater the thickness of the coating, the smaller the wear value *m*, the exception is the coating obtained with a thickness of 2.5 mm. This is due to the increased brittleness of the high-chromium hard alloy coating.

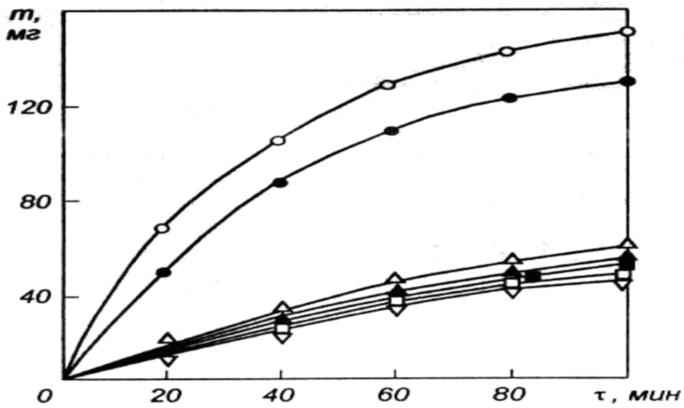


Fig.2. Influence of carbide coatings and heat treatment on the magnitude of abrasive wear: ○ and ● - base material (medium carbon steel with 0.35% C) without coating and without heat treatment and after quenching with 900°C, vacation at 200°C, respectively; Δ, ▲, □ and ■ samples of carbide coatings obtained from coating with a thickness of 1,0, 1,5, 2,0, 2,5 mm, without heat treatment; ◇ - sample with coating derived from a coating thickness of 0.5 mm, after quenching and tempering 900°C 200°C.

Quenching samples with hard-alloy wear-resistant coatings with a heating temperature of 9000C has very little effect on wear resistance, since it is mainly determined by the properties of carbides on the surface of coatings. An increase in the quenching temperature is accompanied by an increase in the amount of residual austenite, a decrease in microhardness and an increase in the amount of wear. If you use heat treatment with double phase recrystallization, the amount of wear is reduced by almost 50% (Fig. 3).

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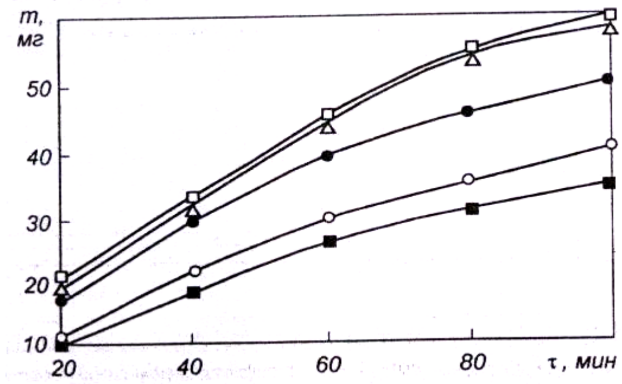


Fig. 3. changes in the abrasive wear of samples with a hard-alloy coating obtained with a thickness of 1.0 mm over time during various heat treatment of samples:●, Δ and □ - quenching with temperatures of 900, 1100 and 1150°C, as well as tempering at 200°C; ■ and ○ - pre-quenching with 1100 and 1150°C, intermediate tempering 6500C, re-quenching with 900°C, tempering at 200°C.

Heat treatment affects not only the wear resistance of the surface, but also the subsurface layers of hard-alloy coatings. This is important for a number of mining machine parts where the allowable wear can be about one millimeter. When comparing the wear resistance of samples with hard-alloy coatings before and after heat treatment, it can be found that the effect of such treatment on the depth of the layer increases: from 7% at a depth of 0.4 mm to 80% at a depth of 0.8 mm.Based on the research conducted, four batches of experimental cultivator paws were produced for field testing, 10 in each batch.

The first batch was manufactured using serial technology from 20 steel, the second from 35ГЛ steel without coatings, the third from 35ГЛ steel with a hard-alloy coating, the fourth from 35ГЛ steel with a hard-alloy wear-resistant coating after heat treatment with double phase recrystallization. The amount of wear of samples was determined by the weight method, after the cultivator worked for a time to process 100-180 hectares of sown hectares. [9.10] We also determined the relative wear resistance of samples in comparison with serial paw cultivators. The results of field tests are shown in table 4.

**Table 4 Results of field tests of cast cultivator paws**

| N° | Test items | Relative wear resistance |
|---|---|---|
| 1. | Ordinary steel 20 | 1.0 |
| 2. | High-carbon steel 0.35%With no carbide coating | 1,2 |
| 3. | High carbon steel 0.35%C with carbide coating | 2,5-3,0 |
| 4. | High-carbon steel 0.35%C with hard-alloy coating after heat treatment with double phase recrystallization | 3,5-4,0 |

We have developed technologies for applying hard-alloy wear-resistant coatings in gasified casting models and subsequent heat treatment with single and double phase recrystallization used in the production of a pilot batch of cast parts and tested in the field on various territories of the Republic. The results of field tests showed that the wear resistance of cast carbide parts is four times higher than in mass-produced machine parts [8].

## IV. CONCLUSION

Summing up, we can conclude that an effective way to increase the abrasive wear resistance is to apply a hard-alloy coating to the working surfaces of the product when casting gasified models. Heat treatment of a hard-alloy coating

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made of a high-chromium hard alloy, performed with double phase recrystallization, forms an optimal structure with a high dislocation density, dispersed secondary and coagulated primary carbides. Heat treatment of a hard-wear coating with double phase recrystallization increases the abrasive wear resistance by almost 50% compared to conventional heat treatment. Therefore, the wear resistance of cast parts is 3.5-4.0 times higher than that of conventional quenching. This technology is implemented at JSC "Uzmetkombinat" with economic effect.

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